공학석사 학위논문

Development of Tomographic Imaging and Fitting Methods for Critical Dimension Measurement of TFT-LCD

Tomographic Imaging과 Fitting 기법을 이용한
TFT-LCD의 Critical Dimension 측정에 대한 연구

2016 년 2 월

서울대학교 대학원
기계항공공학부
노 하 나

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지도 교수 박 희 재

이 논문을 공학석사 학위논문으로 제출함
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기계항공공학부

노 하 나

노하나의 공학석사 학위논문을 인준함

2016 년 2 월

위 원 장 ______________________ (인)

부위원장 ______________________ (인)

위 원 ______________________ (인)

Abstract

Development of Tomographic Imaging and Fitting Methods for Critical Dimension Measurement of TFT-LCD

In this paper, two methods are introduced to enhance the repeatability of critical dimension measurement on certain micro pattern by using White-light Phase Shifting Interferometry (WLPSI). Since WLPSI collects the coherence signal by vertically scanning the sample, the repeatability of WLPSI is often affected by external noise like mechanical vibrations. The external interference to the machine causes numerical error on the measured data. Profile Fitting method is introduced to enhance the repeatability. The fitting parameters are calculated by using iterative non-linear fitting process, Levenberg-Marquart's nonlinear fitting algorithm. Once the fitting parameters are determined, the sampled cross sectioned profile of the mirco-pattern can be interpolated smoothly by fitting process which eventually eliminate possible error factors at the source data. During the Profile Fitting method, the critical dimension data from tomographic image is utilized. Based on the reason, the repeatability of tomographic CD measurement should be stable to achieve for better repeatability. Gaussian Fitting method is suggested for the tomographic image acquisition process to eliminate possible noise properties on the modulus function. In order to evaluate the performance of suggested methods, multiple measurements of pattern samples are conducted.

Keyword: Critical Dimension, TFT-LCD, Micro Pattern, Fitting Method, Tomographic Imaging, White-light Phase Shifting Interferometer

Student Number: 2014-20659

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Abbreviations

CCD	Charge-Coupled Device
CD	Critical Dimension
CS	Column Spacer
MEMS	Micro-electro-mechanical systems
OPD	Optical Path Difference
PS	Photo Spacer
PSI	Phase Shifting Interferometry
TFT-LCD	Thin-film-transistor liquid-crystal display
WLPSI	White-light Phase Shifting Interferometry
WSI	White-light Scanning Interferometry

Symbols

E	Wave Equation of light
I	Light Intensity of coherence signal
I_T	Light Intensity of tomographic image on each pixel
γ	Modulus Function of Coherence Signal
	(also called as Envelope Function)
ϕ	Phase
M	Modulus function (Envelope function)
Z	A cross-sectioned height profile signal

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Chapter 1. Introduction

1.1 Background

Interferometry is widely used instrument that is used to measure different kinds of dimensions such as heights, widths, depths and surface tomography by analyzing coherence signals. Compared to other metrological instruments like SEM and Profilers, interferometry is a non-contact and non-destructive measuring system which does not compromise measuring targets during the measurement process. Also interferometry has renown for high resolution. Due to such properties, interferometry is frequently used in manufacturing industries such as TFT-LCD, MEMS, semi-conductors, and etc. to measure various dimensions of micro patterns.

The interferometry systems can be categorized by its analyzing methods. Phase Shifting Interferometry (PSI), White-light Scanning Interferometry (WSI), White-light Phase Shifting Interferometry (WLPSI) are the most recognized types of interferometry systems. Among those types, WLPSI is frequently used as an in-situ monitoring machine which measures micro or nano unit elements during the manufacturing processes due to its high resolution and precision.

Throughout the research, multiple methods are suggested to enhance the performance of the Critical Dimension (CD) measurement. Depending on measuring systems and analysis types, the measurement performance differs. To numerically evaluate the performance of CD measurement the repeatability of conventional methods and suggested methods will be compared.

1.2 Purpose of Research

This research focuses on the enhancement of CD measurement with WLPSI system by using both height and tomographic data. There are many factors that affects the repeatability of CD measurements. There are many possible influential factors of measurement performances such as mechanical vibrations, scanner linearity errors, imbalanced light distribution, image distortions by camera and etc. To overcome the possible error factors and to enhance the measurement performance, two methods are suggested for enhanced repeatability of CD measurements: 1) a profile fitting method and 2) a Gaussian fitting method.

The evaluation of the suggested methods will be evaluated in two categories: accuracy and precision. By comparing repeatability and averaged data of all conventional and new methods, accuracy of the new method is evaluated. The three-sigma repeatability of the measured data is widely considered for precision evaluation in manufacturing industries. Therefore, the precision of the new method can be evaluated by the measurement repeatability.

1.3 Measuring Target

The measuring target for this research is specified to a micro pattern of TFT-LCD panels called a Photo Spacer (PS) or a Column Spacer (CS). In Fig. 1, TFT-LCD is generally manufactured by bonding different layers of glasses on which color filters, transparent circuits, and etc. are applied and coated. Once all the required components are coated on the glasses, the glasses are vacuumed and sealed together. Prior to the sealing process, certain amount of cell gap should be secured in which liquid crystal material is injected later. Among the multiple TFT-LCD components, CS is the one which secures a certain gap between the layers of glasses.

Usually various dimensional properties are analyzed during the micro pattern measurement, and this process is called as CD measurement. The measured CD data are often utilized to monitor the uniformity of patterns during the manufacturing process. In case of CS, uniformity of the pattern is directly related to the amount of injecting liquid crystal materials, therefore, the critical measurement is conducted to monitor uniformity of the pattern and control the defects. The measuring criterial for the CS patterns are usually defined as the dimension of major and minor axis at pre-defined height.

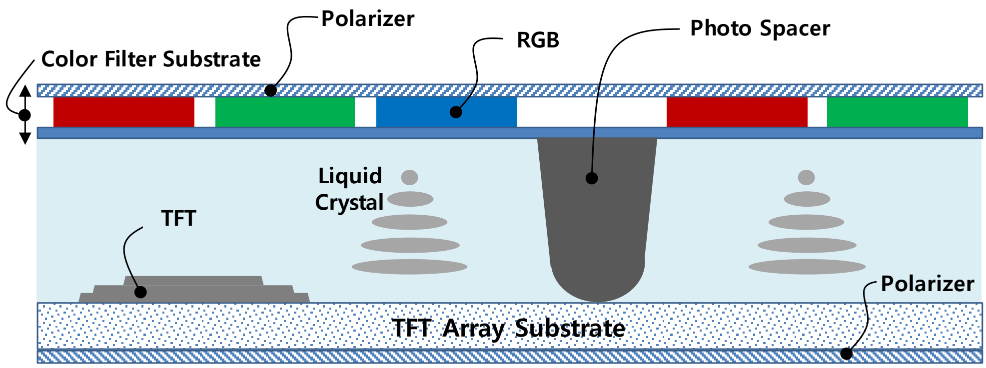
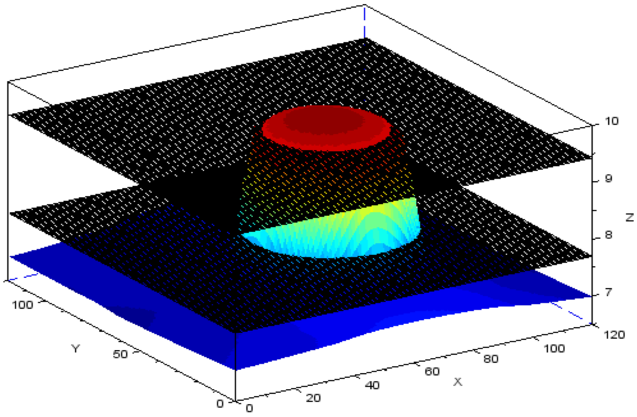


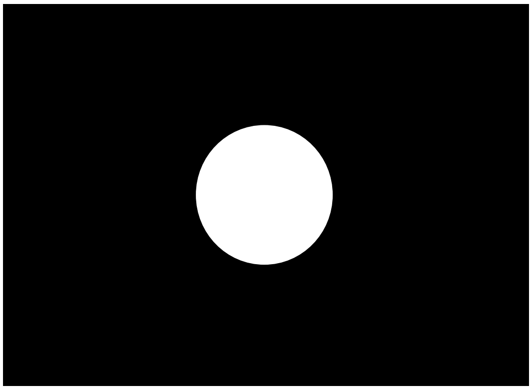
Fig. 1 Simplified Structure of TFT-LCD

1.4 Existing Methods

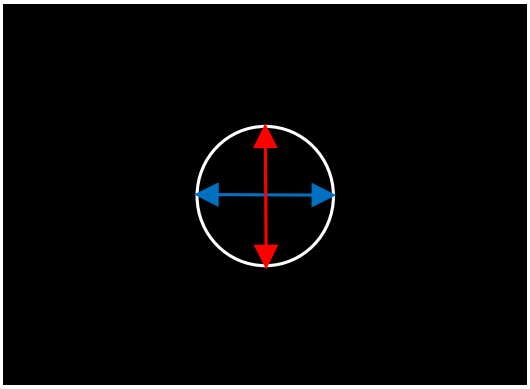
There are different types of CD measurement methods. Commonly, 2D microscopy is used. Once the most focused image is captured with a microscopy system, different kinds of image processing method such as the Laplacian of Gaussian (LoG) filter, the Sobel operator, and etc. are applied to extract edges of micro patterns, and to calculate the dimensions. As the size of micro patterns are getting smaller to nano and sub-nano level, there are physical limitations to get high quality focused images which contains clear intensity contrasts on the edge region. To overcome the limitations, Lee [1] introduces a method that uses subpixel edge detection. The critical dimension can be also measured by using 3D data set. With interferometry system, the 3D height data of entire surface can be calculated by analyzing coherence signals. By cross-sectioning the height data at certain height, it is possible to get the edge info which can be utilized to calculate the critical dimensions. The example of cross-sectioning height method is shown in Fig. 2. Mehta, Sugai and their research team [2] has introduced a method that obtains optically sectioned images at every 1-um step by analyzing 3D height data. Lee [3] and Kim [4] have introduced a new method that uses tomographic images that are created by collecting the most focused intensity of each pixel from coherence signals. Although the analyzing principles of the critical dimension measurement with tomographic images is similar to the 2D image processing techniques, tomographic images are equally focused at any height regions whereas the 2D images are only focused at certain height regions. The example of the critical dimension measurement with tomographic images is shown in Fig. 3. Table 1 compares the properties of each measurement method.



(a) A Micro Pattern (Photo Spacer / Column Spacer)

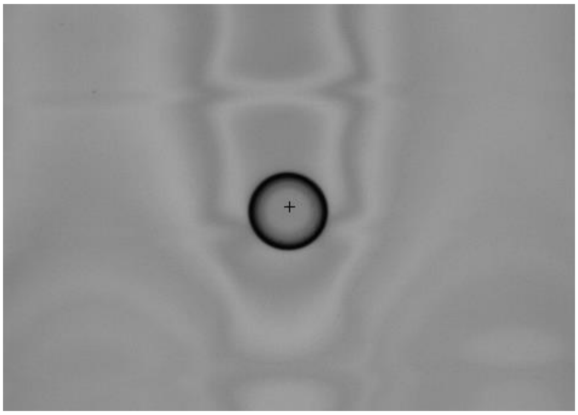


(b) Simpilified Cross-sectioned Veiw at Certain Height

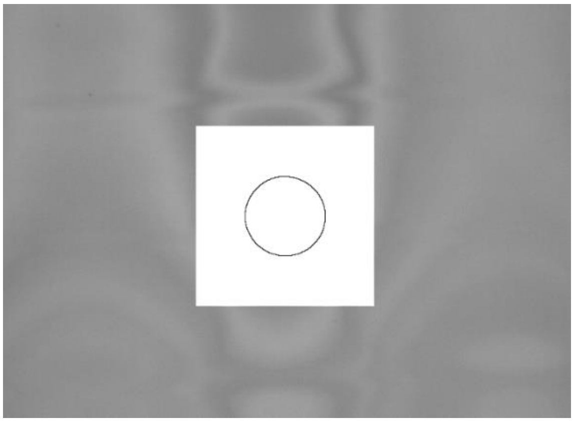


(c) Edge Detection and Critical Dimension Measurement Criteria of a Photo Spacer

Fig. 2 Critical Dimension Measurement with Height Data



(a) A Tomographic Image



(b) Edge Detection and Critical Dimension Measurement of a Photo Spacer

Fig. 3 Critical Dimension Measurement with a Tomographic Image

Table 1 Types of Critical Dimension Measurement Methods

Instruments	Analysis Type	Base Data	Vertical Scanning	Robust to noise	Possible to Measure at Certain Height
Microscopy	2D	Best Focused Image	No Scan	Robust	Impossible
Interferometry	3D	Height Data of Surface	Scan	Weak	Possible
	3D/2D	Tomographic Image	Scan	Robust	Impossible

Chapter 2. Theoretical Background

2.1 White-light Phase Shifting Interferometry (WLPSI)

White-light coherence signal is acquired by vertically scanning the sample. Mirau-type interferometry is used in the experiments. The detailed system configuration is shown in Fig. 4. The emitted light from the light source goes through the beam splitter. The split light travels different optical paths: one goes through reference mirror, and the other goes through measuring sample. By such reason, a difference in optical path occurs. As shown in Fig. 5, the interferometry system vertically scans the sample in certain steps within a period. Once a stack of images is gathered, a coherence signal of each pixel can be acquired by collecting intensities of each pixel.

The acquired coherence signals are processed with the WLPSI algorithm. WLPSI is developed to compensate the weakness of both PSI and WSI. WLPSI combines the positive properties of both algorithms. Ahn [5] has introduced a phase correction method to compensate the WLPSI system. Once the coherence signal is acquired by vertical scanning, the modulus function of a coherence signal is calculated. Then, the peak of the envelope function is evaluated to roughly find relative height of each pixel. Theoretically, PSI system has renown for its high resolution but it has a critical issue, called phase ambiguity. The phase ambiguity can be overcome by finding a rough position with WSI peak prior to the phase calculations. The phase calculation after this process corrects the rough height into an actual compensated height. A series of WLPSI process is configured as Fig. 6.

Once the analysis of WLPSI is done, the relative position of every pixel within the field of view can be calculated. As shown in Fig. 7, the height of certain position can be calculated by comparing the relative positions.

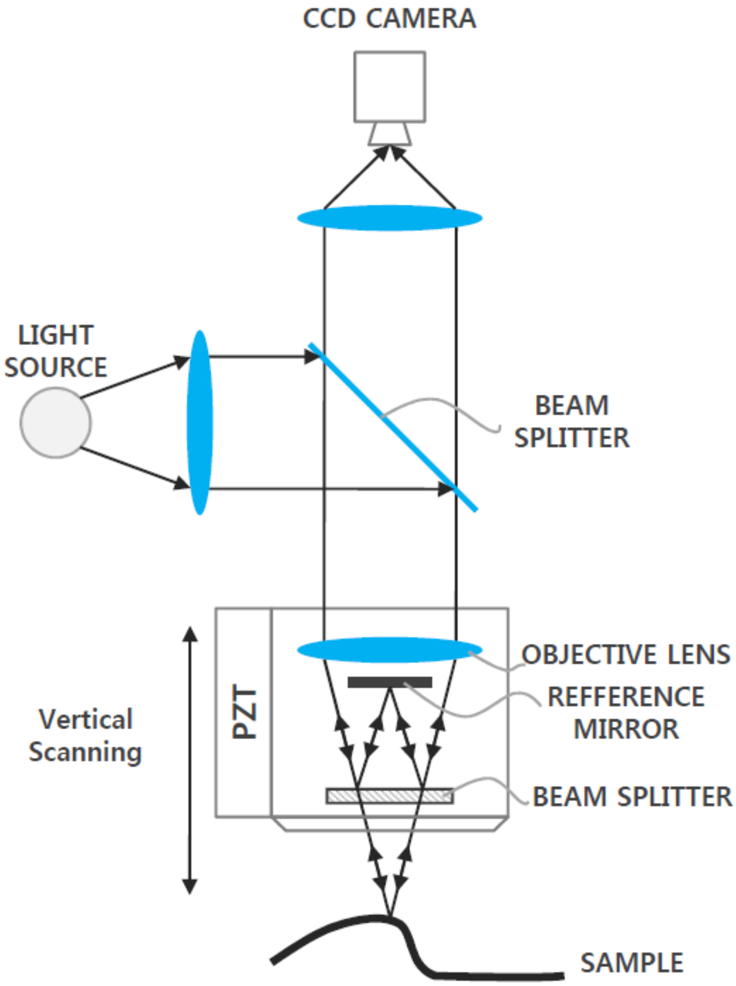


Fig. 4 Mirau-type Interferometry

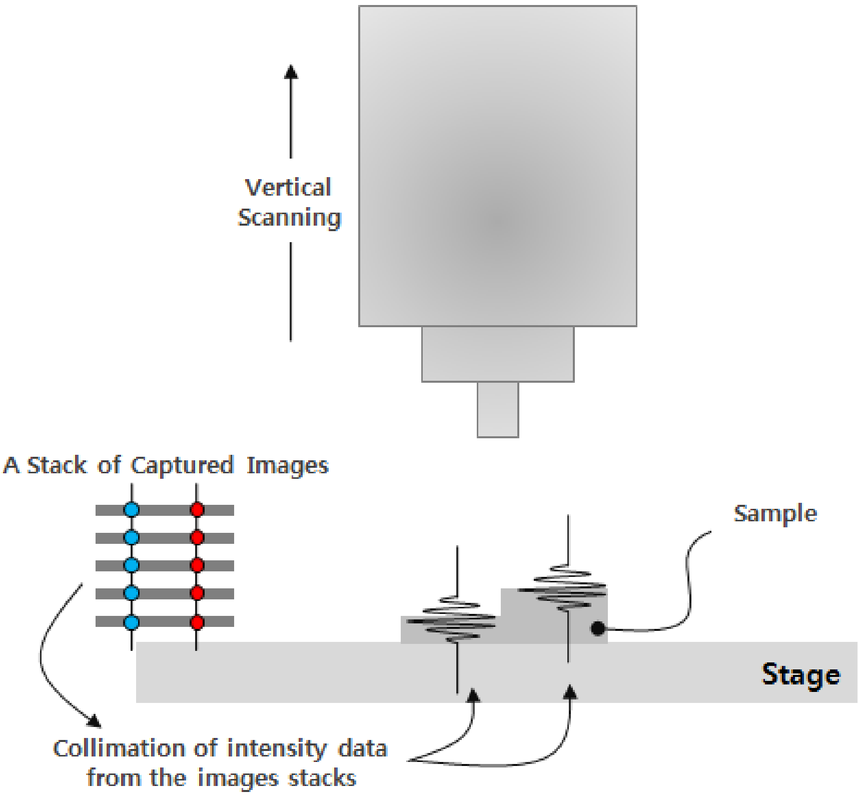


Fig. 5 Vertical Scanning System Configuration and Captured Coherence Signals

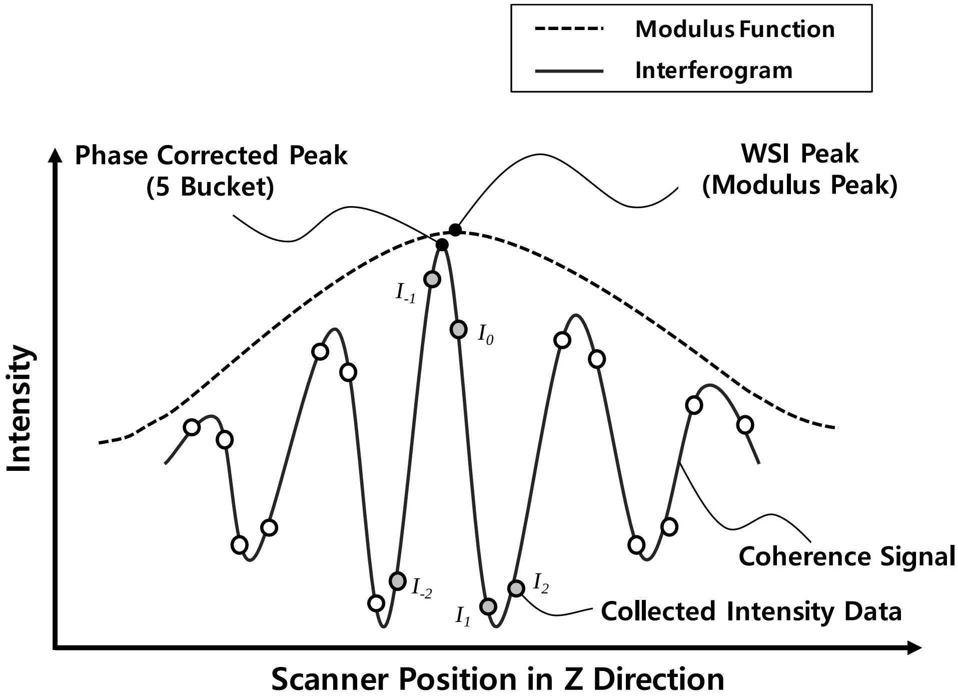


Fig. 6 White-light Phase Shifting Interferometry

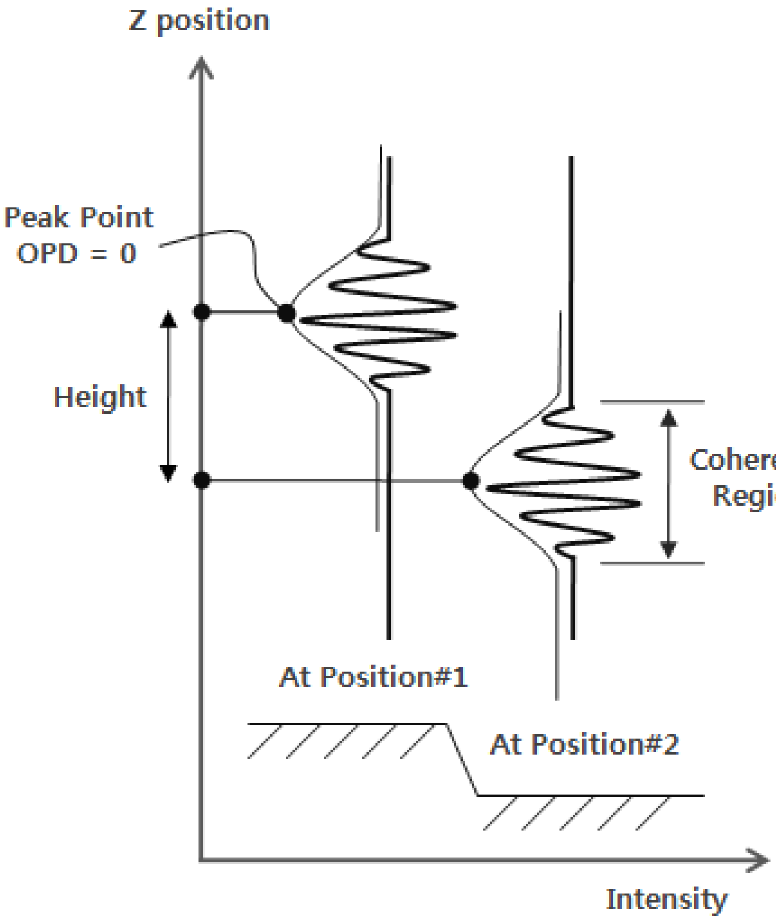


Fig. 7 White-light Coherence Signals at different Height Sample

2.1.1 Equations for a Coherence Signal

In interferometry, one of the two split light paths is changed by the beam splitter component. The two split light paths which travel different optical paths eventually combine together and create interference patterns. This is called as optical path difference (OPD). This OPD results interference on the stack of images that is captured with the CCD camera as shown in Fig.4. Once a stack of images is captured and collected, coherence signals can be created by connecting intensities at a same pixel point. To analyze the coherence signal, the wave equation of light can be expressed as follow:

$$E = E_0 e^{j(\omega t + kx)} \tag{1}$$

In Mirau-type interferometry, if the distance between the beam splitter to reference mirror is l, the height of sample surface is h, and the vertical position of the sample surface is z, the wave equation may be rewritten as follows:

$$\begin{aligned} E_r &= Ae^{j(\omega t + 2kl)} \\ E_s &= Be^{j(\omega t + 2k(l+z-h))} \end{aligned} \tag{2}$$

In equation (2), E_r is a light reflected from the reference mirror, and E_s is a light reflected from the sample surface. The interference of two lights with OPD is captured by CCD Camera, and the intensity of the light combination can be expressed as follows:

$$\begin{aligned} I(z) = \ & |E_r + E_s|^2 = (E_r + E_s)(\overline{E_r + E_s}) \\ & = A^2 + B^2 + 2ABcos\big(2k(h - z)\big) \end{aligned} \tag{3}$$

From the equation (3), the intensity of coherence signals with white-light interferometry can be simply expressed as follows:

$$I(z) = I_{avg} + \gamma cos(\phi_{ref} - 2k\Delta z) \quad (4)$$

In equation (3) and (4), A^2+B^2 represents the average intensity (I_{avg}). 2AB represents the visibility envelope function (also known as a modulus function, γ) which is determined by factors such as reflectance of measuring sample, numerical aperture of the objective lens and frequency distribution of light source. If the reflectance of measuring sample and numerical aperture of the objective lens are assumed to be constant, the shape of envelope function is determined by the shape of the frequency distribution of the light source. For example, if the frequency distribution of the light source is Gaussian shape, the envelope function forms a Gaussian shape [6].

2.1.2 Modulus Function Calculation

The first analyzing step of the WLPSI system is to extract modulus function of the coherence signal. By analyzing the modulus function, the relative position along the scanning direction can be calculated: the peak of the modulus function indicates the height position. There are different types of analytical methods for modulus function calculation. Chim and Kino [7] have used Fast Fourier Transform (FFT) method to extract the envelope function of the coherence signal. Later, for more reduced calculation load, Chim and Kino [8] also used Hilbert Transform to calculate the envelope function.

2.1.3 Phase Calculation

In 1996, Larkin [9] has introduced a new method that uses a bucket algorithm to calculate the modulus function and phase of coherence signals. Compared to other methods, Larkin's method maintains performance as others with simpler and less calculation load. Therefore, in this research, Larkin's bucket algorithm is used to find phase and envelope function of the coherence signal. The idea of Larkin's method is originated from Carre's algorithm [10] which uses the compensating property of the five-step algorithm. By simplifying Carre's algorithm, Larkin's equations for phase and modulation equations are introduced as follows:

$$\phi = \tan^{-1}\left\{\frac{[4(I_2 - I_4)^2 - (I_1 - I_5)^2]^{\frac{1}{2}}}{-I_1 + 2I_3 - I_5}\right\} \tag{5}$$

$$\mathrm{M} = \frac{(\mathrm{I}_2 - \mathrm{I}_4)^2\{[4(\mathrm{I}_2 - \mathrm{I}_4)^2 - (\mathrm{I}_1 - \mathrm{I}_5)^2] + (-\mathrm{I}_1 + 2\mathrm{I}_3 - \mathrm{I}_5)^2\}^{\frac{1}{2}}}{4(I_2 - I_4)^2 - (I_1 - I_5)^2} \tag{6}$$

This equation is based on the five-step (5-bucket) algorithm. For faster calculation, Larkin uses M^2 instead of M.

$$4\mathrm{M}^2 \sin^4\psi = (I_2 - I_4)^2 - (I_1 - I_3)(I_3 - I_5) \tag{7}$$

$$\mathrm{M}^2 \propto (I_2 - I_4)^2 - (I_1 - I_3)(I_3 - I_5) \tag{8}$$

2.2 Tomographic Image

The tomographic Image can be created by analyzing the coherence signals. The optic parts of interferometer have certain limitation of empirically achievable maximum slope. [11] If the surface of the sample has slope over certain amount, the optics may not receive the reflected light from the sample. Therefore, at the high slope regions, the coherence signals are weakened and create a dead zone as shown in Fig. 8(a). Lee [3] and Kim [4] use these properties to create tomographic images, and the principles are as follows.

The coherence region and the edge region can be differentiated by using the visibility index as Equation (9). The coherence signal at the edge region has significantly low visibility index compared to ones at the coherence regions.

$$\mathrm{V} = \frac{I_{MAX} - I_{Min}}{I_{Max} + I_{Min}} \tag{9}$$

Theoretically, the tomographic image is created by collecting maximum intensity of coherence signals. Equation (10) is used to acquire similar intensity distribution of the tomographic image as focused images with a 2D microscopy system. Equation (10) uses the maximum values of the coherence signal intensities and acquire Tomographic image intensity, I_T.

$$I_T = \frac{\mathrm{R_S}}{\rho \cdot (1-\rho) \cdot (R_M + R_S + 2\sqrt{R_M \cdot R_S})} \cdot I_{D(Max)} \tag{10}$$

R_s and R_M represents the reflectance of a sample and reference mirror respectively. ρ represents transmittance of the beam splitter. I_D represents the intensity at detection plane (same as intensity of a coherence signal), and in this case the maximum intensity is utilized.

The coherence signals at edge region does not have enough visibility for analysis. Therefore, the maximum intensity is utilized as tomographic image intensity, I_T.

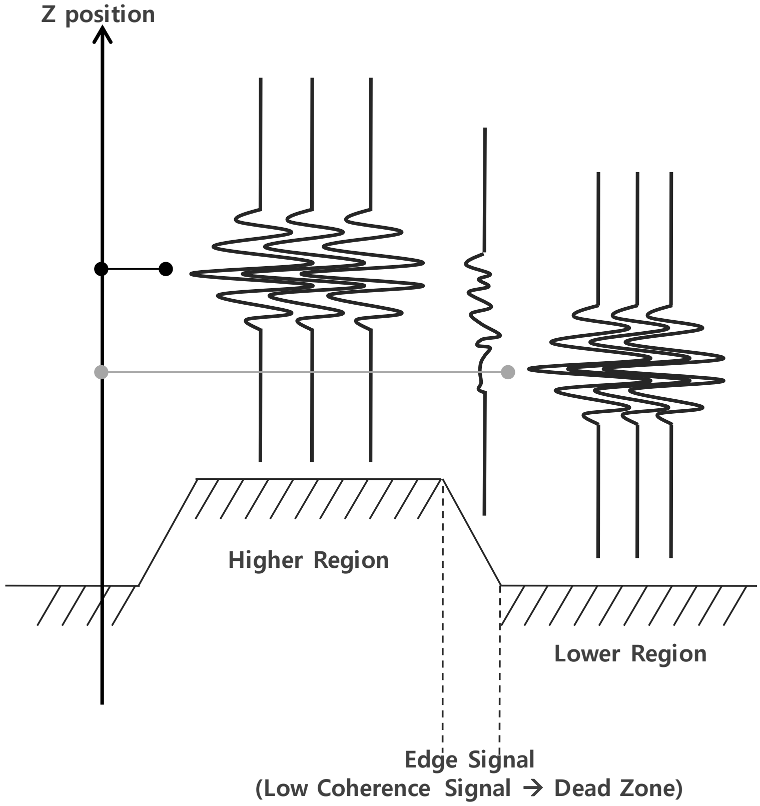
$$\mathrm{I_T}(X, Y) = I_{MAX}(X, Y) \tag{11}$$

Once all the coherence signals of every pixel are analyzed with Equation (10) and Equation (11), a Tomographic image can be formed as Fig. 8(b) by collecting tomographic intensities ($\mathrm{I_T}$) together.

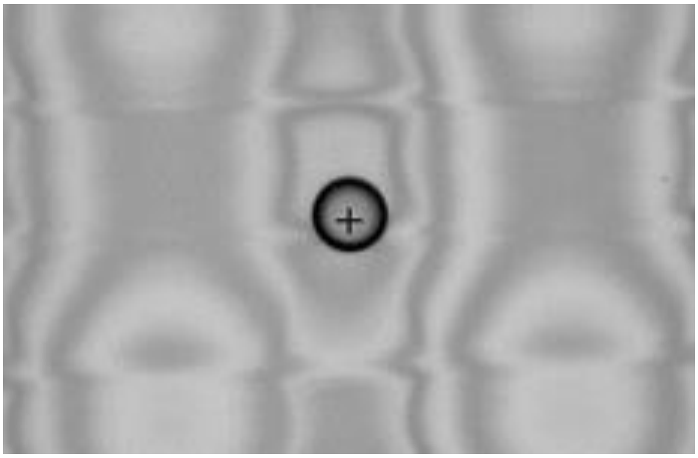
To reduce the computational load during calculation of the tomographic image intensities. Lee has suggested the RMS methods. Lee's RMS method uses the characteristic of the coherence signal which has big intensity different between coherence and edge regions. As shown in Equation (12), the visibility factors such as maximum and minimum intensity of sampled coherence signals are used to calculate the tomographic image intensity, I_T. [3]

$$\mathrm{I_T}(\mathrm{X}, \mathrm{Y}) = \sqrt{I_{MAX}(X, Y)^2 + I_{MIN}(X, Y)^2} \tag{12}$$

Once tomographic images are acquired, multiple edge extraction techniques such as Laplacian of Gaussian (LoG) filter and Canny edge detection algorithm are applied to conduct CD measurement.



(a) Strength of Coherence Signal and Dead Zone



(b) Tomographic Image with Lee's RMS Method

Fig. 8 Tomographic Image of a Mirco Pattern

Chapter 3. Fitting Methods

3.1 Profile Fitting Method

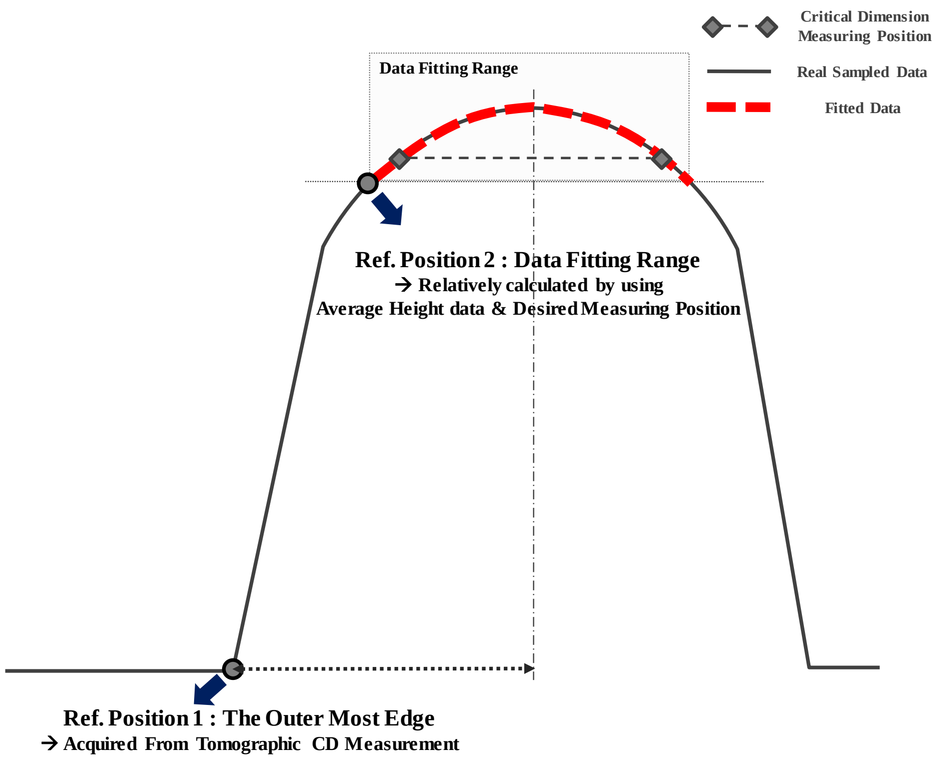
For more precise CD measurement of CS, this paper presents Profile Fitting Method. The basic principle of the Profile Fitting Method can be categorized in three steps: 1) sample 3D data collection, 2) fitting parameter calculation and 3) CD analysis.

By using the sample 3D data, the cross-sectioned profile of major and minor axis of CS is extracted as shown in Fig. 9(a). The top part of CS is not circular or elliptical shape. Depends on the manufacturer, some CS has flat part on the very top section, therefore, the top section is divided in half, and modeling function is applied to each half section with sigmoid functions. Equation (13) is the modified sigmoid function that is used for the profile fitting process.

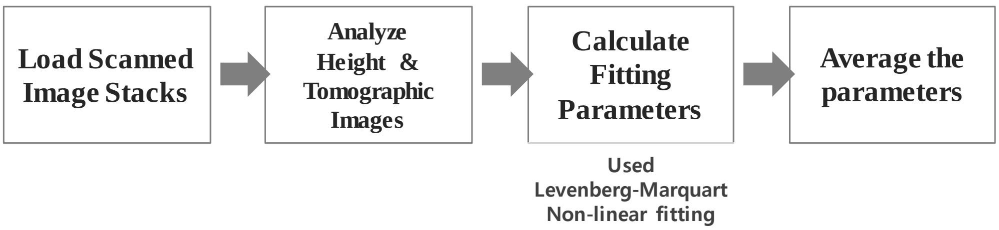
$$\mathrm{Z(x)} = \mathrm{H} * \left(\frac{2}{1 + e^{-M(Ax-B)}} \right) + C \tag{13}$$

A, B and C represents the position of the selected fitting regions, H represents the scale factor of the curve, and M represents the slope of the curve. During the fitting process, A, B and C parameters are the constants that are calculated by using position of the cross-sectioned profile and the CD result by analyzing Tomographic images. M is the only unknown that should be determined by non-linear fitting process. To calculate the modeling parameters, Levenberg-Marquart non-linear fitting algorithm is used.

By iteratively fitting the sampled data to the modified sigmoid equation, the fitting parameters are calculated. Once the representative fitting parameters are determined, the critical dimension at certain height for each measure data can be analyzed by the equation with the fitting parameters.



(a) A Corss-sectioned View of a CS and its Fitting Retion



(b) Steps of Parameter Calculation

Fig. 9 Schematic Diagrams of Profile Fitting Method

3.2 Gaussian Fitting Method

In Profile Fitting method, the parameters reference the CD measurement data from Tomographic image. Gaussian Fitting methods is suggested to give additional enhancement in repeatability. In Section 2.2, the maximum intensity of coherence signal is the key factor to create a tomographic image. The intensity at the peak position of the envelope function represents the intensity at the most focused position, therefore, it is used as the maximum intensity for the tomographic image. As a result, the peak position of the envelope function is numerically critical to the measurement repeatability.

Theoretically, the envelope function has the same shape as the frequency spectrum of the light source. Fig. 10 shows the frequency spectrum of white-light LED. Since a yellow filter is used within the interferometric system, the first peak part is filtered out, and only the second Gaussian shaped spectrum represents the frequency spectrum of the light source. Therefore, the ideal shape of the interferogram should be a Gaussian shaped as shown in Fig. 11.

When there are external interferences like mechanical vibrations, the coherence signal includes noise data. The noise factors add error on the coherence signals, and the shape and position of the envelope function changes. In Fig. 12, the real coherence signal which consists the vibration error within the envelope function is shown. The shape of the envelope function in Fig. 12(b) has two peaks instead of having one. This may cause some error while finding the maximum position of the envelope functions. Fitting the envelope function to the Gaussian function is suggested to compensate the possible noise factors within the signals. Equation (14) is the Gaussian function that is used to fit the envelope function. Levenberg-Marquart non-linear fitting algorithm is used to fit the sampled data to Equation (14).

$$\mathrm{f(x)} = ae^{-\frac{(x-b)^2}{2c^2}} \qquad (14)$$

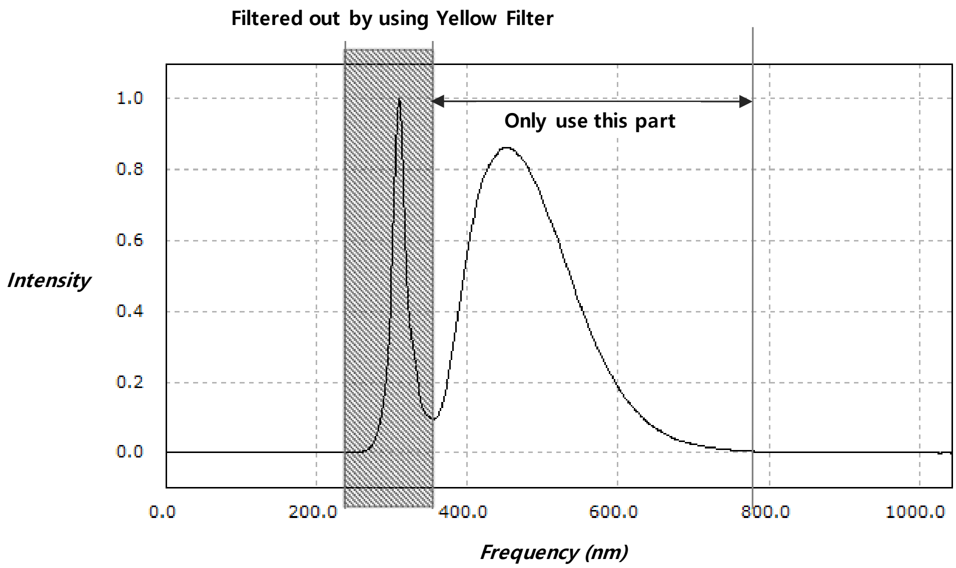
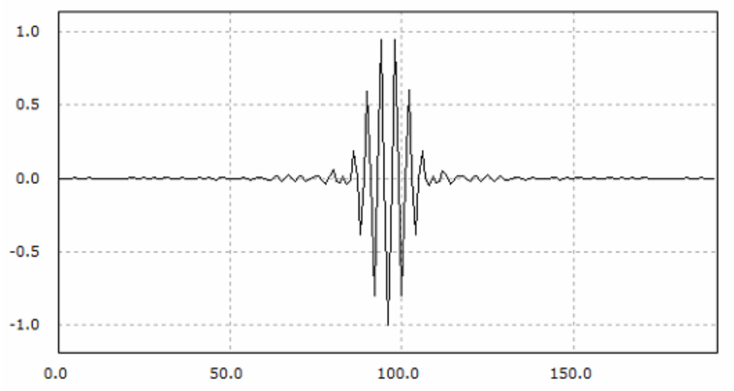
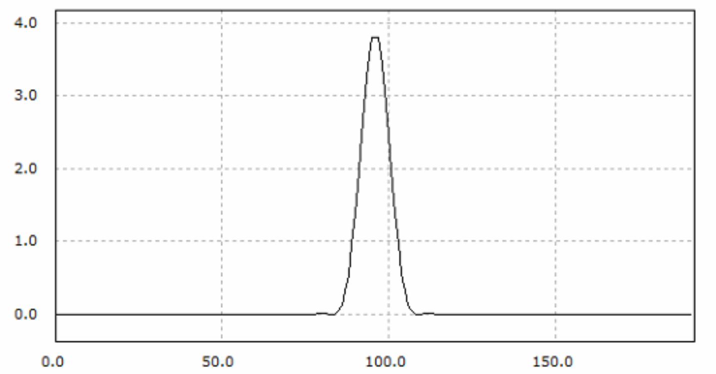


Fig. 10 Shape of of LED Light Source Spectrum

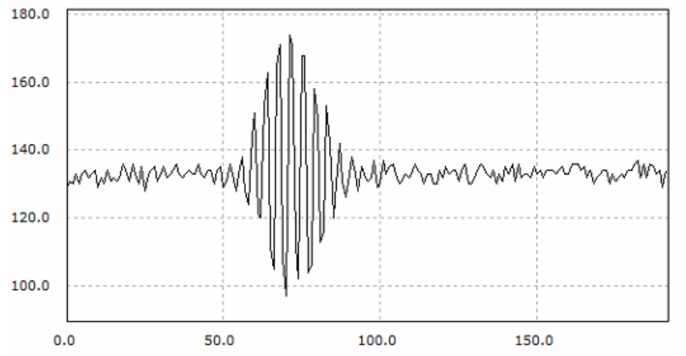


(a) Simulated Coherence Signal

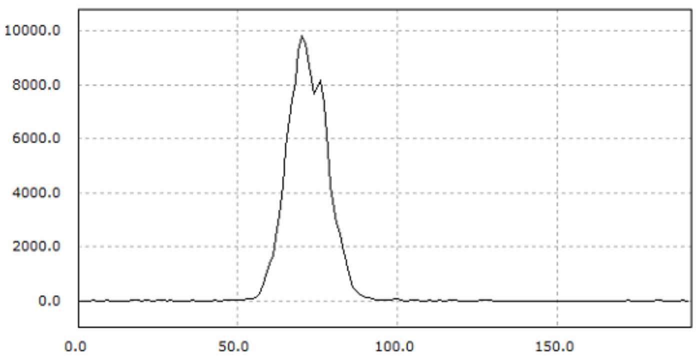


(b) Modulus Function (Larkin) of (a)

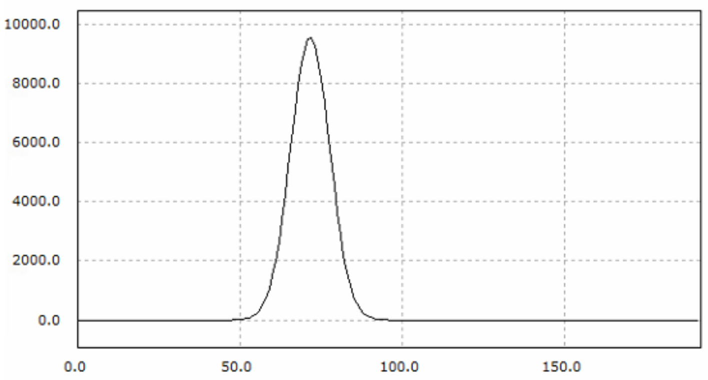
Fig. 11 Simulated Coherence Signal and its Modulus function



(a) Real Coherence Signal



(b) Modulus Function of (a)



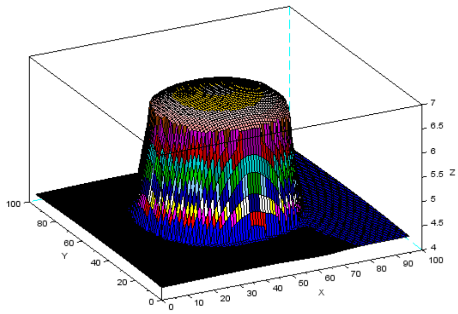
(c) Modulus Function (Gaussian Fit)

Fig. 12 Real Coherence Signal and its Modulus functions

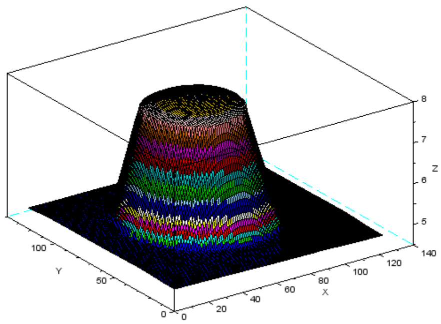
Chapter 4. Experimental Results

Multiple TFT-LCD samples are measured to evaluate the suggested methods. Three different column spacer samples are measured by a Mirau-type interferometry system, and the system settings for each sample are shown in Table 2. The shapes of three column spacer samples are shown in Fig. 13.

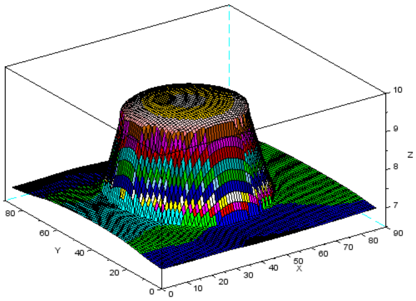
The experiments are conducted in following three ways: 1) implementing fitting method only, 2) implementing Gaussian fitting method only, and 3) implementing both methods together. The experiment is conducted by measuring the same point 20 times. The averaged dimension is calculated by averaging the obtained dataset, and the repeatability of the measurement is calculated by multiplying three to the standard deviation of the repetitively measured data. The results are compared with a conventionally measured data which is analyzed by cross sectioning the 3D height data at certain height. The implementation results are shown as Fig. 14 to Fig. 16 and Table 3 to Table 5.



(a) Sample No. 1



(b) Sample No. 2



(c) Sample 3

Fig. 13 Shape of Three Measured Column Spacer Samples

Table 2 Instrument Setting Conditions for Each Sample

Conditions	**System Type**	**Lens Settings**	
		Zoom	**Objective**
Sample 1	Mirau Type Interferometer	0.5x	50x
Sample 2		1.0x	20x
Sample 3		0.5x	20x

4.1 Enhancement in Repeatability

As shown in the result figures and tables, by implementing suggested methods, the repeatability of CD measurement is improved. By using Profile Fitting method, the repeatability is decreased up to 19.57% of the conventionally calculated data. By implementing Gaussian Fitting method, the repeatability is decreased up to 33.41% of the conventionally calculated data. Once both methods are applied together, the more synergetic results have obtained. The repeatability is reduced up to 18.98%, which is the lowest repeatability among the results of different analysis methods. These results verify that both methods enhance the repeatability of CD measurements.

4.2 Accuracy of Implemented Data

Once a different analytical method is applied, the change in measured data is inevitable. The changes in each measured data causes change in the averaged data. The averaged data are analyzed for the reliability analysis. The degrees of data agreement between suggested methods and the conventional method are calculated by a following equation:

$$\text{Reliability } (\%) = \frac{|New - Conventional|}{Conventional} * 100 \qquad (15)$$

In this research, if the reliability percentage is under 5%, the result is presumably accepted as precise. According to the experimented results, the reliability percentages of Profile fitting method, Gaussian fitting method and Both methods are under 3.80%, 0.24% and 2.50% respectively. The results indicate that the measured data of the suggested methods are as reliable as the conventional method.

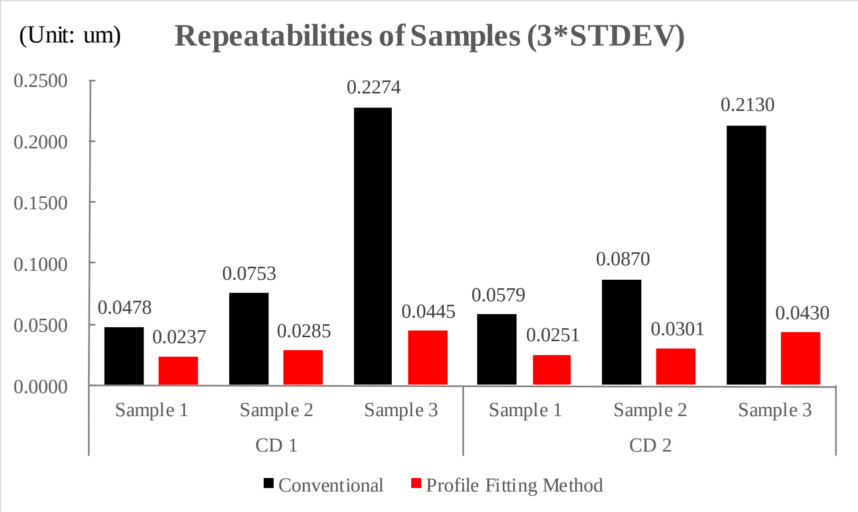


Fig. 14 A Result with Conventional Method and Profile Fitting Method

Table 3 Implemenataion Results of Profile Fitting Method and Comparison

Averaged Measured Value	Sample 1		Sample 2		Sample 3	
	CD1	CD2	CD1	CD2	CD1	CD2
Conventional (um)	8.4327	8.5593	16.4677	16.3581	18.8727	19.3096
Profile Fitting (um)	8.3495	8.4103	16.0834	15.7363	18.7609	19.2599
Reliability (%)	**0.99%**	**1.74%**	**2.33%**	**3.80%**	**0.59%**	**0.26%**

(a) Comparison of Averaged Data

3*STDEV	Sample 1		Sample 2		Sample 3	
	CD1	CD2	CD1	CD2	CD1	CD2
Conventional (um)	0.0478	0.0753	0.2274	0.0579	0.0870	0.2130
Profile Fitting (um)	0.0237	0.0285	0.0445	0.0251	0.0301	0.0430
%	**49.53%**	**37.90%**	**19.57%**	**43.31%**	**34.62%**	**20.21%**

(b) Comparison of Repeatabily

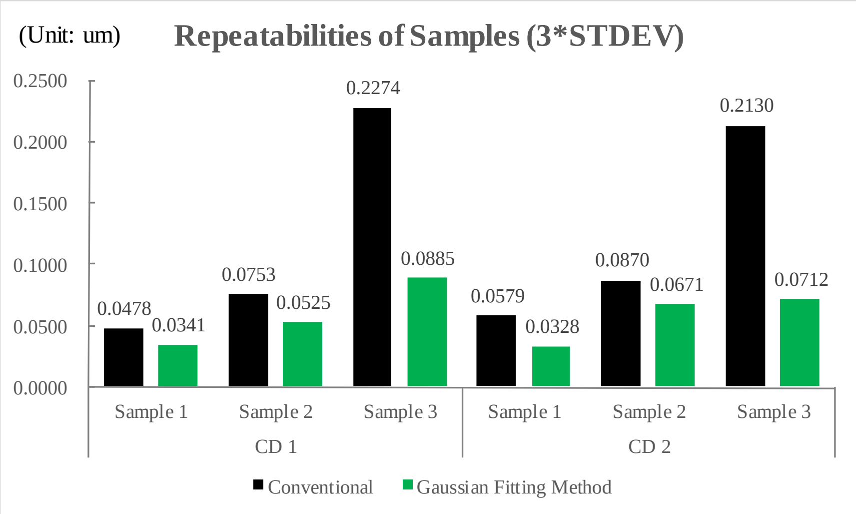


Fig. 15 A Result with Conventional Method and Gaussian Fitting Method

Table 4 Implemenataion Results of Gaussian Fitting Method and Comparison

Averaged Measured Value	Sample 1		Sample 2		Sample 3	
	CD1	CD2	CD1	CD2	CD1	CD2
Conventional (um)	8.4327	8.5593	16.4677	16.3581	18.8727	19.3096
Gaussian Fitting (um)	8.4313	8.5506	16.4786	16.3700	18.8362	19.2625
Reliability (%)	**0.02%**	**0.10%**	**0.07%**	**0.07%**	**0.19%**	**0.24%**

(a) Comparison of Averaged Data

3*STDEV	Sample 1		Sample 2		Sample 3	
	CD1	CD2	CD1	CD2	CD1	CD2
Conventional Method (um)	0.0478	0.0753	0.2274	0.0579	0.0870	0.2130
Gaussian Fitting (um)	0.0341	0.0525	0.0885	0.0328	0.0671	0.0712
%	**71.48%**	**69.80%**	**38.92%**	**56.61%**	**77.09%**	**33.41%**

(b) Comparison of Repeatabily

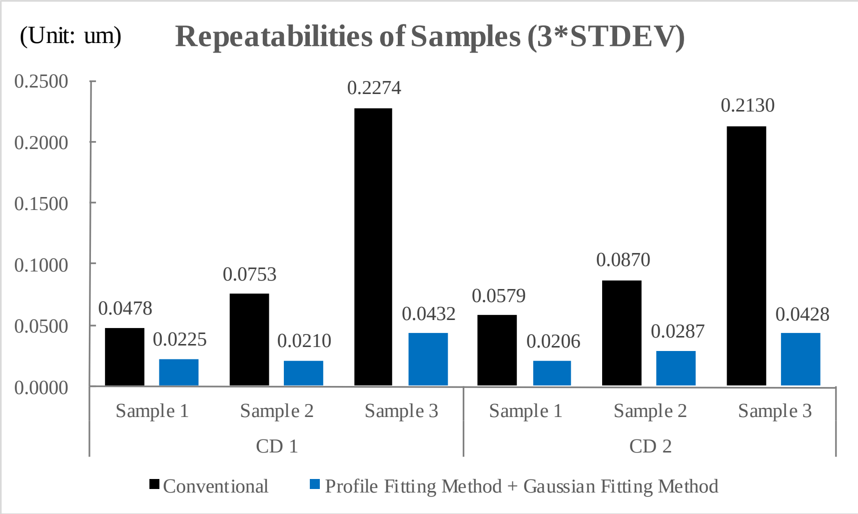


Fig. 16 A Result with Conventional Method and Profile Fitting + Gaussian Fitting Methods

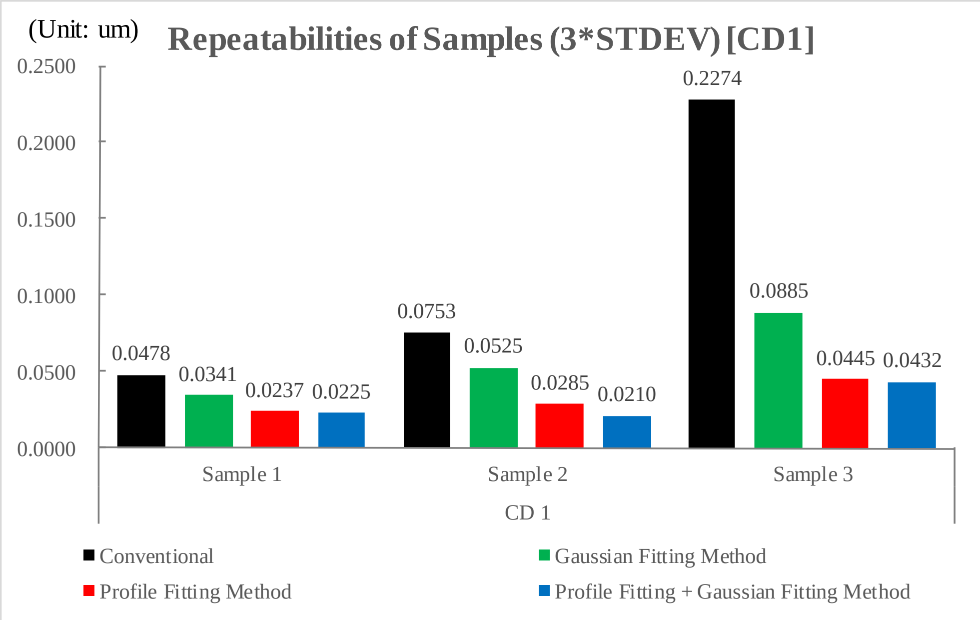
Table 5 Implemenataion Results of Both Fitting Methods and Comparison

Averaged Measured Value	Sample 1		Sample 2		Sample 3	
	CD1	CD2	CD1	CD2	CD1	CD2
Conventional Method (um)	8.4327	8.5593	16.4677	16.3581	18.8727	19.3096
Both Methods (um)	8.3424	8.4101	16.1166	15.9938	19.3436	19.3520
Reliability (%)	**1.07%**	**1.74%**	**2.13%**	**2.23%**	**2.50%**	**0.22%**

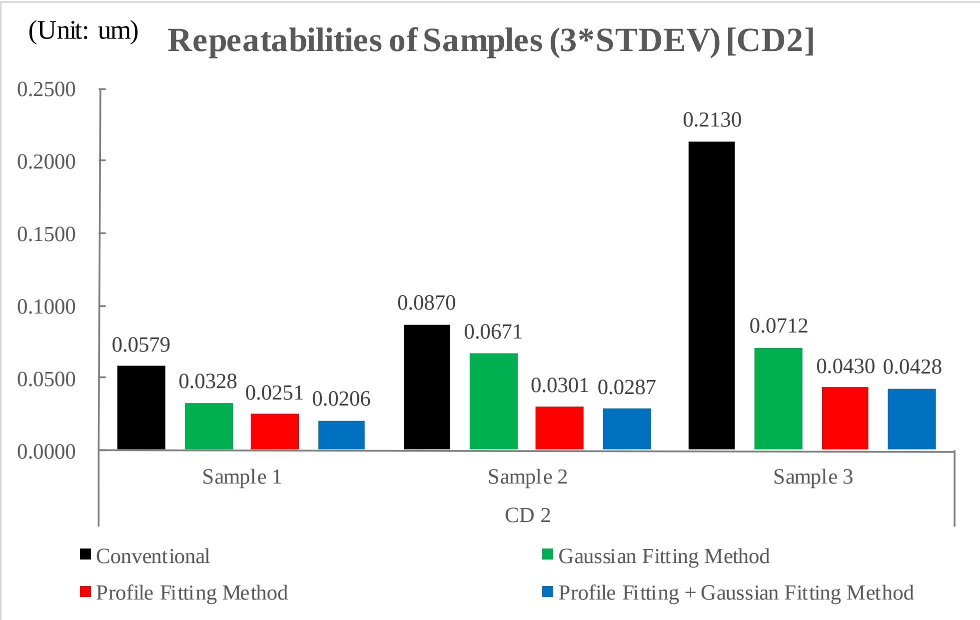
(a) Comparison of Averaged Data

3*STDEV	Sample 1		Sample 2		Sample 3	
	CD1	CD2	CD1	CD2	CD1	CD2
Conventional Method (um)	0.0478	0.0753	0.2274	0.0579	0.0870	0.2130
Both Methods (um)	0.0225	0.0210	0.0432	0.0206	0.0287	0.0428
%	**47.03%**	**27.83%**	**18.98%**	**35.61%**	**32.97%**	**20.11%**

(b) Comparison of Repeatabily



(a) Repeatability of Critical Dimension 1



(b) Repeatability of Critical Dimension 2

Fig. 17 Repeatability Comparison of Different Methods

Chapter 5. Conclusion

In this thesis, two types of fitting methods are proposed to decrease the repeatability of critical dimension measurement of pattern and enhance the performance of tomographic measurements. Three different CS samples are measured and analyzed with the two suggested methods, and results are evaluated by repeatability and averaged dimension.

Profile Fitting method uses a modified sigmoid equation to find the representative fitting parameters of measuring samples. Once the fitting parameters are calculated by its iterative non-linear fitting process, the CD can be measured from the fitted cross-sectioned profile. The experiment with three different CS samples has confirmed that the repeatability reduces up to 19.57% of the conventional repeatability result while the difference in averaged dimension stays under 3.8%.

Gaussian Fitting method is applied to compensate possible error factors like mechanical vibrations to the envelope function. By implementing Gaussian fitting process, the repeatability reduces up to 33.4% of the conventional repeatability result. The difference in averaged dimension of the Gaussian Fitting method stays under 0.24% which turns out to be the best among all the experiments.

To verify the synergy of both methods, both Profile Fitting method and Gaussian Fitting method is applied together. Throughout the samples, the lowest repeatability is acquired, and the averaged dimension of the measured data stays within the acceptable range (under 2.50%).

In conclusion, the suggested two fitting methods reduce repeatability of CD measurement while keeping the accuracy of measured data.

References

[1] 이일환, 서브픽셀 정밀도의 경계추출을 이용한 TFT-LCD 형상 측정 시스템, 서울대학교: 박사학위논문, 2005.

[2] D. S. Mehta, M. Sugai, K. Hinosugi, S. Saito, M. Takeda, T. Kurokawa, H. Takahashi, M. Ando, M. Shishido and T. Yoshizawa, "Simultaneous three-dimensional step-height measurement and high-resolution tomographic imaging with a spectral interferometric microscope," *Applied Optics,* vol. Vol. 41, no. No. 19, pp. 3874-3885, July 2002.

[3] 이동성, Tomographic imaging을 이용한 in-lined LCD 형상 검사 시스템 개발, 서울대학교: 박사학위논문, 2004.

[4] 김유식, 백색광 간섭계를 이용한 이차원 이미지 획득에 관한 연구, 서울대학교: 박사학위논문, 2009.

[5] 안우정, 백색광 위상천이 간섭계에서의 위상 오차의 수치해석 보정, 서울대학교: 박사학위논문, 2005.

[6] 강민구, “백색광 주사 간섭계를 이용한 표면 형상 측정 알고리즘에 관한 연구,” 한국과학기술원 : 박사학위논문, 1998.

[7] S. S. Chim and G. S. Kino, "Correlation microscope," *Optics Letters,* vol. Vol. 15, no. No. 10, May 1990.

[8] G. S. Kino and S. S. Chim, "Mirau correlation microscope," *Applied Optics,* vol. Vol. 29, no. No. 26, Sep. 1990.

[9] K. G. Larkin, "Efficient nonlinear algorithm for envelope detection in white light interferometry," *Optical Society of America,* vol. Vol. 13, no. No. 4, pp. 832-843, April 1996.

[10] P. Carre, "Installation et utilisation du comparateur photoélectrique et interférentiel du Bureau International des Poids et Mesures," *Metrologia,* vol. Vol. 2, no. No. 1, pp. 13-23, Sep. 1966.

[11] D. Malacara, Optical Shop Testing, 3rd Ed. ed., Wiley, 2007.

[12] H. Gavin, “The Levenberg-Marquardt method for nonlinear least squares curve-fitting problem,” Department of Civil and Environmental Engineering, Duke University, 2011.

Abstract in Korean

Tomographic Imaging 과 Fitting 기법을 이용한 TFT-LCD 의 Critical Dimension 측정에 대한 연구

노하나
기계항공공학부
서울대학교 공과대학교

본 논문에서는 두 가지의 피팅 기법을 이용하여 백색광 위상 천이 간섭계를 활용한 TFT-LCD의 주요 요소인 Column Spacer (CS)의 Critical Dimension (CD) 측정의 반복능 향상에 대한 연구이다. 백색광 위상 천이 간섭계는 측정 대상의 수직 스캔을 통해 측정대상의 높이를 구한다. 이때 주변 환경의 상태에 따라 기계적 진동과 같은 노이즈가 포함되게 되면 위상의 오차가 발생되고, 측정 결과의 반복능이 저하되는 결과가 발생된다.

CD 측정의 반복능 향상을 위해 첫번째 형상 피팅 방식을 제안하였다. 형상 피팅 방식은 간섭계를 활용하여 CS의 높이 형상 데이터 샘플을 수집하고 수집한 데이터를 제안된 수식을 이용하여 피팅을 적용한 후 계산된 파라미터를 기준으로 CD 측정 시 CS의 상부의 노이즈가 포함된 데이터를 모델링하여 평활화 시켜주는 작용을 한다. 이를 통해 노이즈가 감소된 데이터의 CD를 구하게 되면 반복능이 향상되는 효과를 가져올 수 있다. 형상 피팅을 진행할 때 Tomographic 이미지를 활용하여 계산된 CD 측정 값을 기준 값으로 사용하게 되는데, 이는 Tomographic 이미지의 CD 측정 반복능이 중요하다는 의미가 된다. 이를 위해 가시도 함수에 가우시안 피팅을 적용하는 방식이 제안되었다.

제안된 두 가지의 피팅 방식의 유효성을 검증하기 위해 세가지의 TFT-LCD 샘플을 이용하여 CS를 측정하였고, 반복능의 향상도를 확인하였다. 또한, 평균 측정값의 변동 정도 계산을 통해 각 방식들의 정확도를 평가하였다.

키 워 드 : Critical Dimension, TFT-LCD, Micro Pattern, Fitting Method, Tomographic Imaging, White-light Phase Shifting Interferometer

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